Self-Analysis of CCD Image Sensors using Dark Current Spectroscopy

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CCD image sensors have long been known to be very sensitive to contaminants in the fabrication process as, for example, in the case of "white spot defects" ascribed to heavy metals (Fig. 1). We have exploited this sensitivity to develop a useful tool for investigating dark current in the image sensors themselves. By integrating over a number of frame times and analyzing pixel statistics, it is possible to observe quantized dark current from individual deep-level traps present in the imager [1,2]. These traps are Poisson-distributed among the imager pixels and may result from contamination in the starting substrates or the fabrication process. The detection sensitivity of this technique can be below 10^9 traps/cm^3. By combining dark current analysis with investigations of deliberate imager contamination [3], we have found at least four deep-level traps and have identified three due to Au, Co, and Ni. We have measured the temperature dependence of these traps and determined their distinctive dark current generation rates. Our results show that as few as three Co or Ni traps in a pixel can produce a white spot or dim point defect that can affect device performance or yield.

This method of imager analysis, which we call dark current spectroscopy, additionally separates the dark current into its constituent parts for evaluation and comparison, as shown in Fig. 2 for an interline CCD imager. Figure 2a compares the dark current of the vertical CCD shift registers with that of the photodiodes. Surface state contributions increase the CCD dark current over that of the pinned photodiodes; however, the CCD noise, averaged out by the clocking, is much more uniform and of less consequence than that of the photodiodes. The expanded photodiode spectrum in Fig. 2b separates the dark current component Jo common to all the photodiodes from the added contributions of individual bulk traps. This spectrum indicates the presence of two different traps, identifiable from their dark current generation rates in the figure as a ubiquitous, unknown trap and a low level of gold, present at 10^9 traps/cm^3. Using dark current spectroscopy, one can nondestructively monitor production runs of imagers for the presence of such contaminants at levels below those currently thought to affect yield.

[1] R. D. McGrath, J. Doty, G. Lupino, G. Ricker, and J. Vallerga, "Counting of deep-level traps using a charge-coupled device," *IEEE Trans. Electron Devices*, vol. ED-34, pp. 2555-2557, 1987.

[2] W. C. McColgin, J. P. Lavine, J. Kyan, D. N. Nichols, and C. V. Stancampiano, "Dark current quantization in CCD image sensors," *IEDM Tech. Digest*, pp. 113-116, Dec. 1992.

[3] W. C. McColgin, J. P. Lavine, J. Kyan, D. N. Nichols, J. B. Russell, and C. V. Stancampiano, "Effects of deliberate metal contamination on CCD imagers," *Mater. Res. Soc. Symp. Proc.* vol. 262, San Francisco, CA 1992, pp. 769-774.

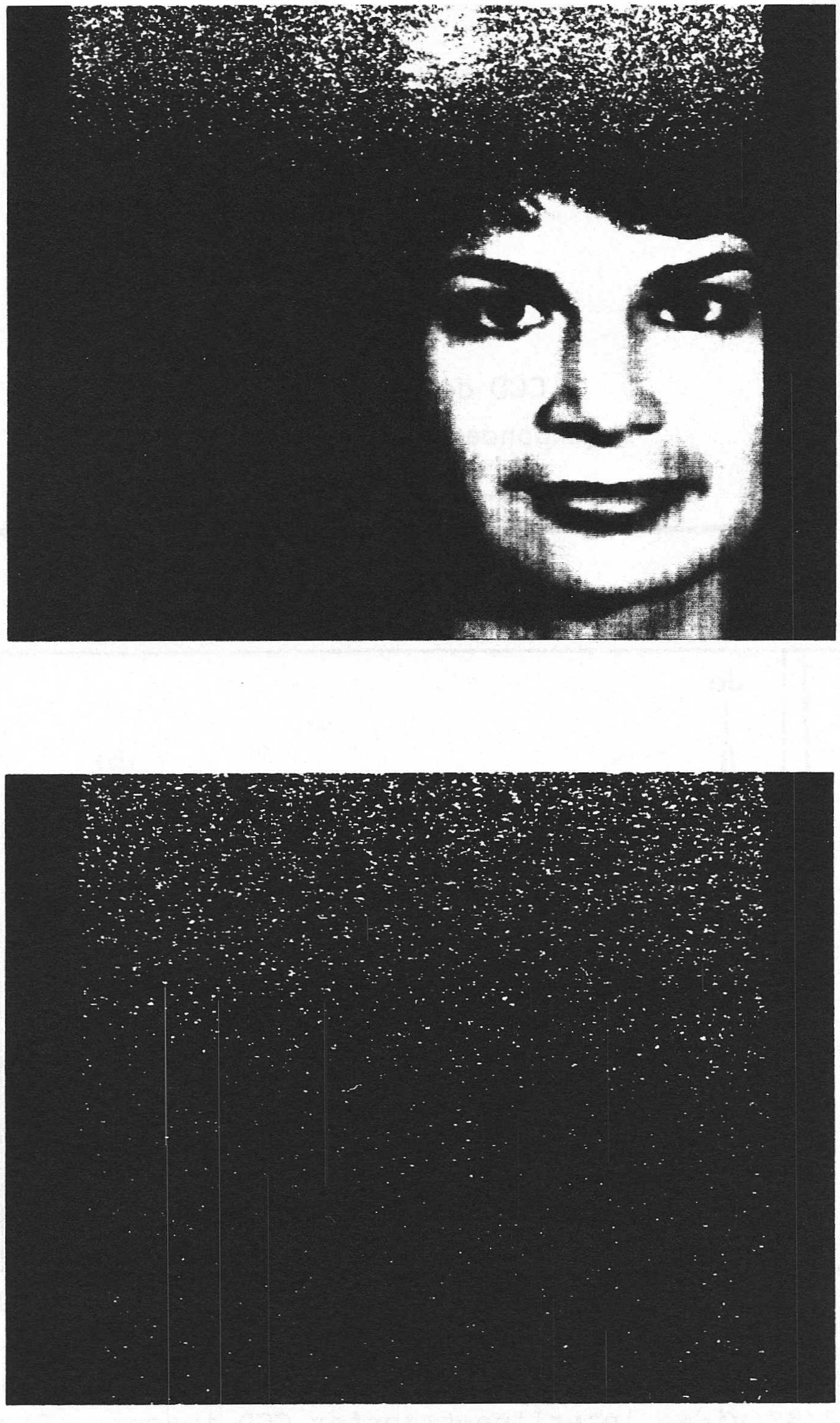


Figure 1. TV monitor photographs from imagers deliberately contaminated with metals. Top: the band of isolated bright-point defects lies over a backside iron scribe line. Bottom: dim-point defects have diffused out from the cobalt line scribed near the top of the image.

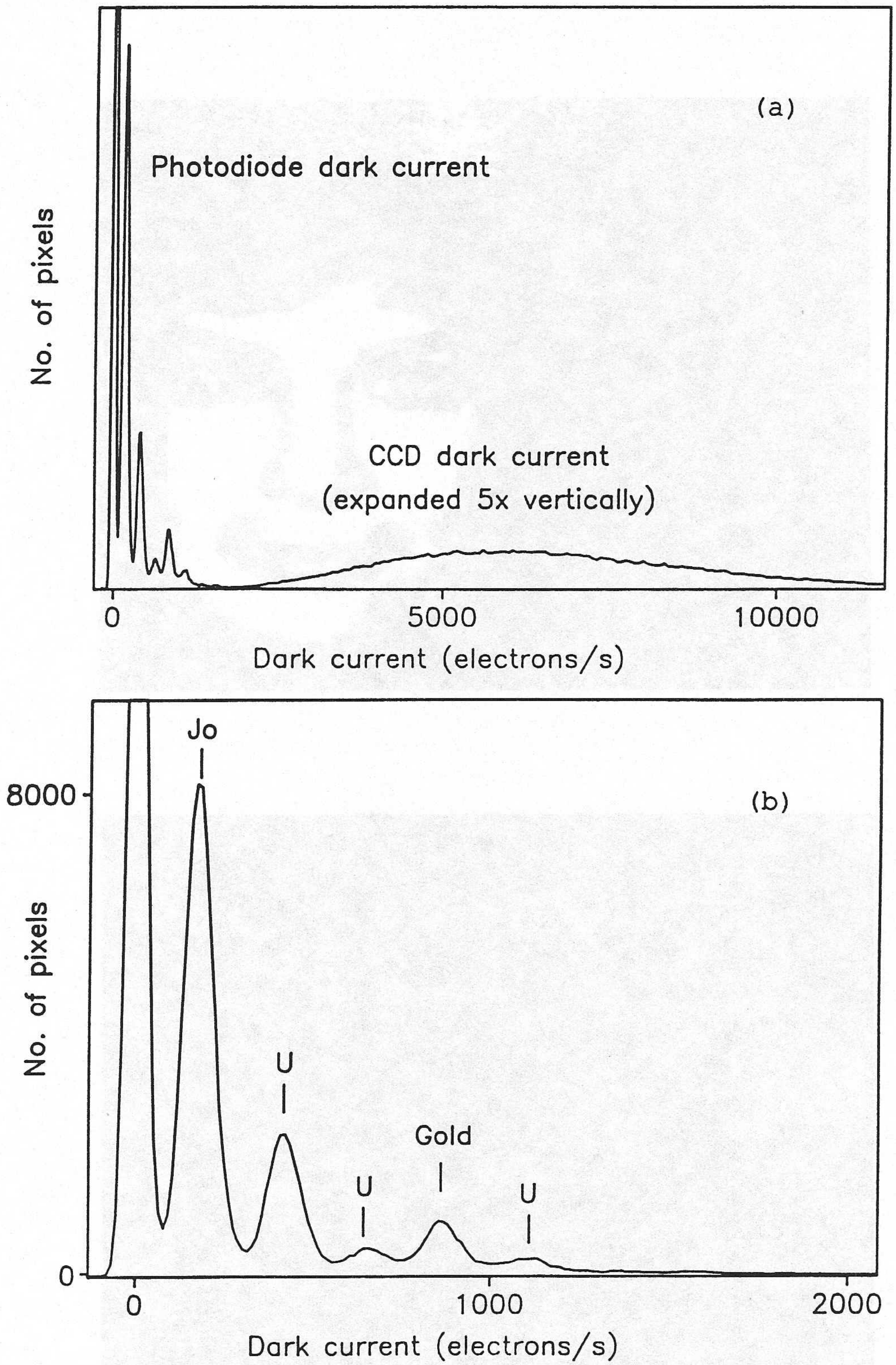
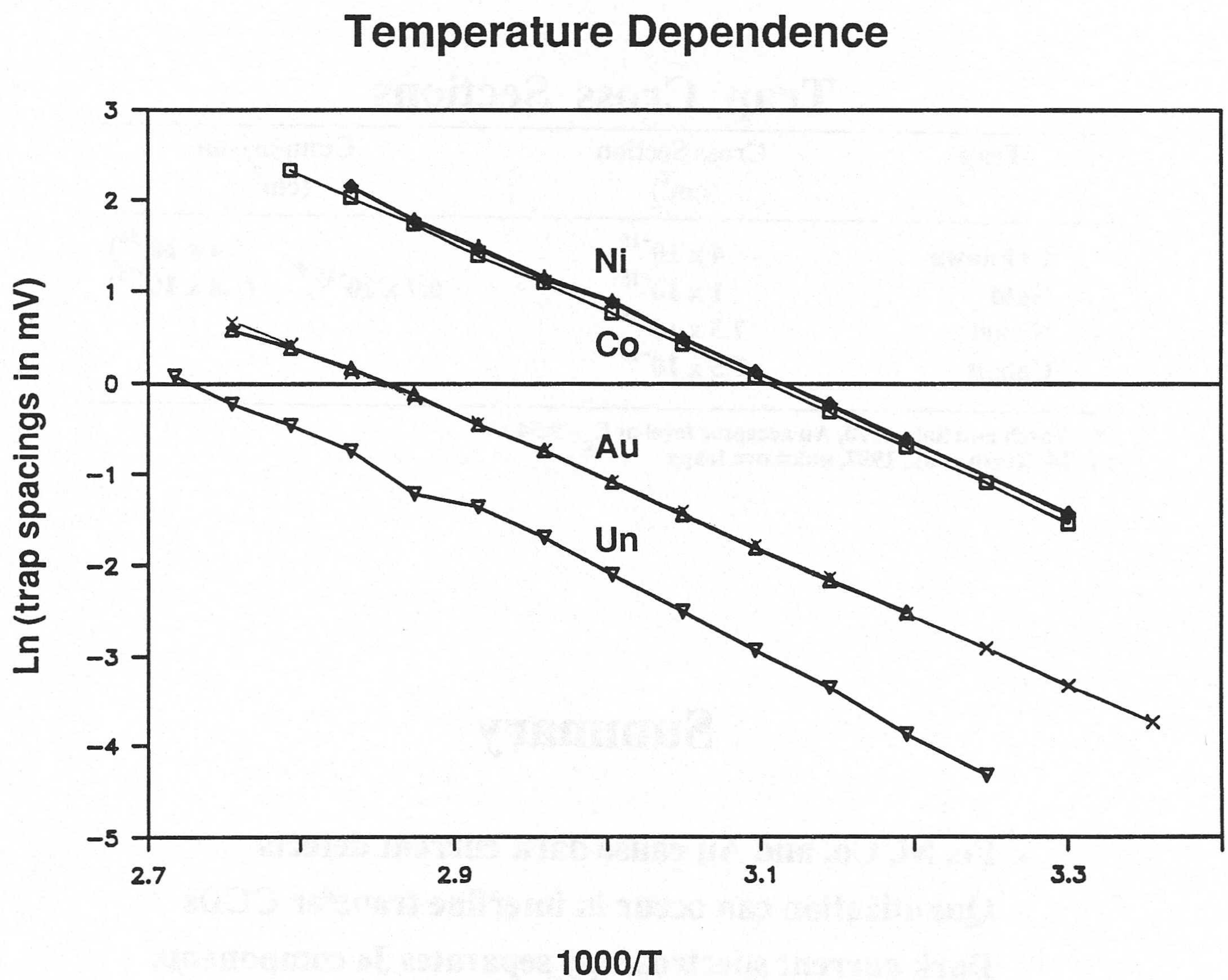


Figure 2. Dark current components of a KODAK KAI-0370 Image Sensor, a 2/3" video interline-transfer CCD imager. Fig. 2a compares the dark current of the CCDs with that of the pinned photodiodes, shown also in expanded form in Fig. 2b. The truncated peak is a zero dark current reference marker. The photodiodes share a common dark current component Jo and show quantized contributions from two deep-level traps -- an unknown trap and one due to gold contamination.



Temperature dependence of four different traps using dark current spectroscopy. Cobalt, Ni, and Au trap levels are all near mid-gap. The unknown trap level is off mid-gap.